Precise Positioning of Autonomous Underwater Vehicle in Post-processing Mode

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Abstract

Autonomous Underwater Vehicles plays specific role in underwater investigation. Generally, this kind of vehicles will move along a planned path for sea bottom or underwater installations inspections, search for mineral deposits along shelves, seeking lost items including bottom mines or for hydrographic measurements. A crucial barrier for it remains the possibility of precise determination of their underwater position. Commonly used radionavigation systems do not work in such circumstances or do not guarantee the required accuracies. In the paper some new solution is proposed on the assumption that it is possible to increase the precision by certain processing of a combination of measurements conducted by means of different techniques. Objective of the paper is the idea of navigation of AUV which consists of two phases: firstly a trip of AUV along pre-planned route and after that post-processed transformation of collected data in post-processing mode. During the processing of collected data the modern adjustment methods have been applied, mainly estimation by means of least squares and M-estimation. Application of these methods should be associated with the measuring and geometric conditions of navigational tasks and thus suited for specific scientific and technical problems of underwater navigation. The first results of computer aided investigation will be presented and the basic scope of these application and possible development directions will be indicated also.

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Keywords: Underwater navigation, Autonomous Underwater Vehicle.

1. Introduction

The features of underwater robots commonly known as Autonomous Underwater Vehicles render it's more and more popular. Initially, the military applications in this field were dominating, but in recent years the more widespread civilian utilization of these types of vehicles has been observed. The most interesting features of AUV are a time of their underwater staying, resistance to strain, possibility of carrying more sensors that any human being could and finally, a physical resistance to adverse factors. Unfortunately the precision of moving along planned path and precision of positioning are at the moment not satisfactory. Lot of possible applications need high accuracy, for example to perform such tasks as inspection of sea bottom or underwater installations, seeking lost items or taking hydrographic measurements.

The commonly used radio navigation systems are in this case useless, as radio waves do not propagate in the water. The alternative inertial systems are still not enough precise or too expensive in relation to cost of AUV. Therefore creation of alternative method of underwater navigation systems is still very attractive.

The proposition referred in the paper concerns in accurate fixing executed by AUV way after it returns, not in the real time, as usually in the navigation it is realised. So it could allow us heightening a precision collected by AUV information about the objects observed on the bottom along the passed way.

2. General notices

It is assumed that in processing of underwater observation data collected by AUV the advanced adjustment methods are to be applied. Application of these methods should be associated with measuring a geometric conditions of navigational tasks thus adapted to suit specific scientific and technical problems of underwater navigation. The following are such issues' examples:

a. Planned motion of an underwater vehicle;
b. Precise recording of the movement;
c. Possibility of taking precise measurements in water environment;
d. Precise determination of underwater or bottom objects' positions, which constitutes a part of referred navigation system.

We do not discuses a fundamental technical problem which is associated with a vehicle structure, a quality of the equipment installed on board and adequacy of autopilot operation to the vehicle dynamics which are fundamental for question a) and b). Although expensive, modern inertial systems are featured by properties nearing the expectations for them and therefore it was assumed that the above problem will not be undertaken in this paper.

The c) problem is closely associated with the knowledge about sea bottom image and a possibility to obtain information about characteristic elements of the sea bottom correlated with information about its coordinates. Different algorithms of comparative method of navigation have been tested for it and will be reported in the next part of the paper.

The d) problem is a typical analytic one, possible for solving with modern methods of mathematical estimation. A precision of navigation is dependant on coordinates' accuracy of aids to navigation and geometry of its collocation and finally a quality of the observations. Therefore in this part the adjustment methods, used successfully as an example in geodesy, may play an important role.

At the beginning we should notice different strategies of AUV resulting from different tasks. We propose to divide it into 5 groups:

1) Delivering
2) Guarding;
3) Searching
4) Delivering;
5) Inspection;
6) Scanning;

For the first three groups precise navigation is not so critical, because in last stage of trajectory usually some TV camera or similar scanning techniques are used. The real challenge for navigation is inspection or scanning some area for bathymetric works or monitoring sea bottom, where AUV should pass precisely along pre-planned path. It means to pass rather long broken line.

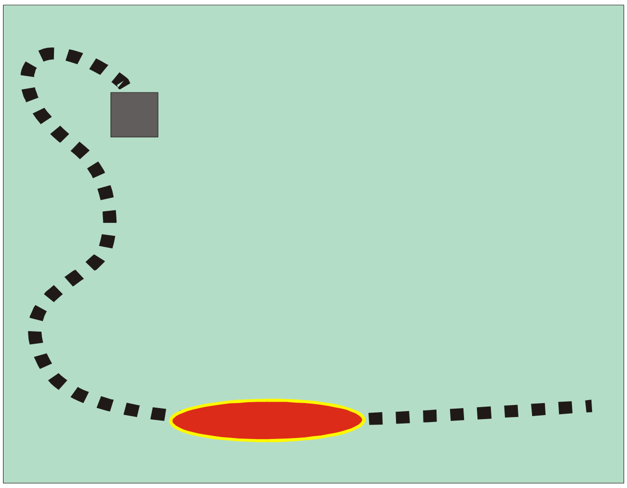

Figure 1. Idea of DELIVERING strategy.

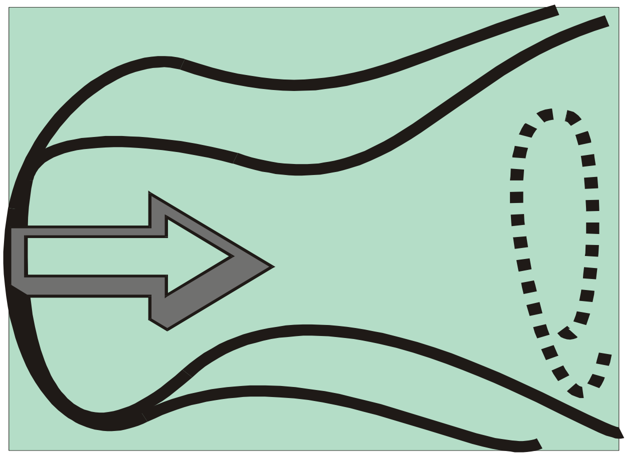

Figure 2. Idea of GUARDING strategy.

The pure inertial system isn't good for this activity because of accumulating character of errors. The negative sides of acoustic systems are difficulties in delivering into different places. Additionally, in many cases the trip of AUV lasts for teens miles and in shallow waters it is difficult to warrant such long range.

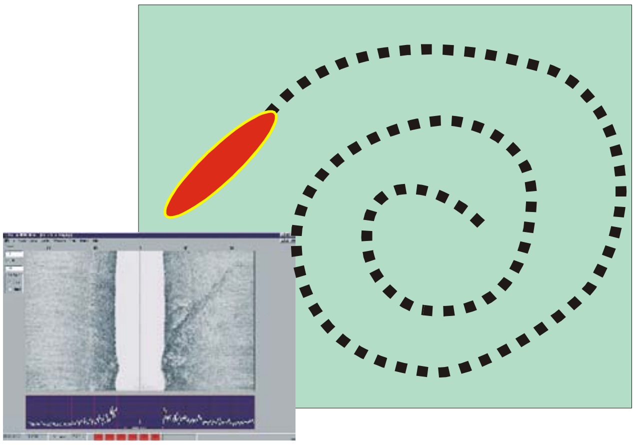

Figure 3. Idea of SEARCHING strategy.

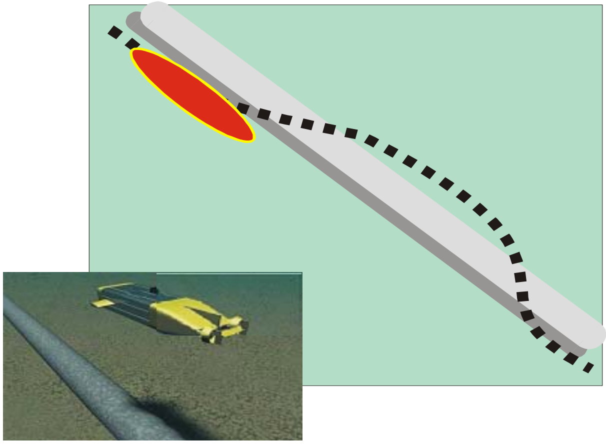

Figure 4. Idea of INSPECTION strategy.

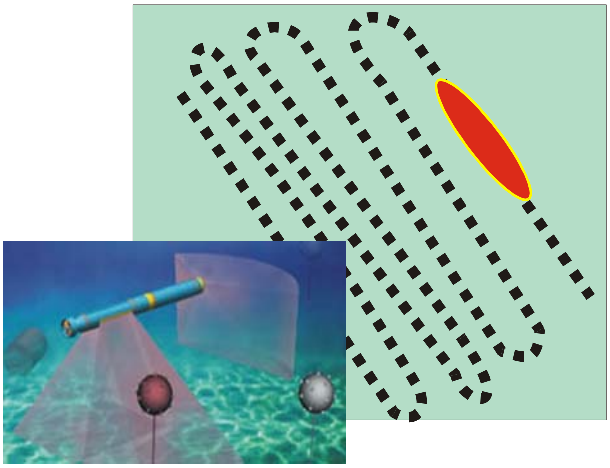

Figure 5. Idea of SCANNING strategy.

Let assume the chance to increase the precision by certain processing of a combination of measurements, conducted simultaneously with different techniques. The objective of the paper is the new idea of AUV navigation, consisted of two phases: firstly - a trip of AUV along a pre-planned route not necessary with extremely high accuracy, and secondly the post-processed transformation of data collected by AUV.

Additionally possibilities of images similarities' technique in the first stages has been tested, as the bathymetry field is rather stable and any changes in it need a lot of work and time. In the second stage the modern adjustment methods would be applied, resulting from general estimation rules, mainly the estimation by means of the least squares and M-estimation.

It is very important to notice that scanning the sea bottom or inspection of some region means to calculate the coordinates of bottom object distinguished on the bottom or the places of depth measurements, not to realise planned track with the ideal accuracy. This is though – the better accuracy of AUV trajectory will effect in more accurate position of bottom object, but it doesn't means it isn't possible to determine position of object with good accuracy - passing the planed trajectory with pure accuracy. The real limitation in such thinking is to warrant wider range of scanning equipment than width of scanned path.

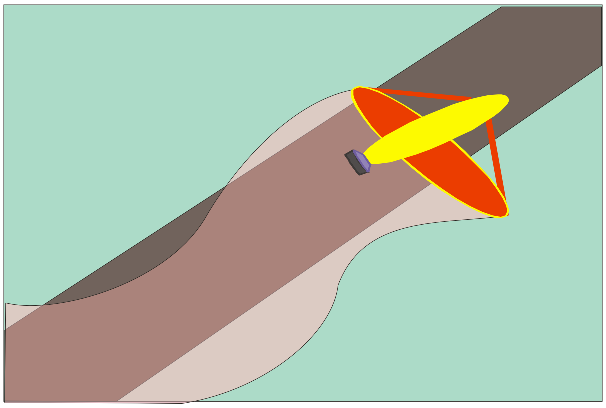

Figure 6. Comparison of planned and realised paths.

3. On Adjustment Methods in Underwater Navigation

Let assume that $\mathbf{x} \in \Re^n$ is a vector of the measured values and $\mathbf{X} \in \Re^m$ is the object coordinates vector (underwater vehicle position vector), while n > m. Let's assume that vectors $\mathbf{x}$ and $\mathbf{X}$ are linked by an observation set of equations:

$$\mathbf{x} = \mathbf{F}(\mathbf{X}) \quad \rightarrow \qquad \hat{\mathbf{x}} = \mathbf{F}(\hat{\mathbf{X}}) \qquad (1)$$

where:

$\hat{\mathbf{x}} = \tilde{\mathbf{x}} + \mathbf{v}$

$\hat{\mathbf{x}}$ - measured values estimator,

$\tilde{\mathbf{x}}$ - measurement results vector,

$\mathbf{v}$ - corrections vector (estimator of measurements real error),

$\hat{\mathbf{X}}$ - coordinates vector estimator,

($\mathbf{F}(\circ)$ - vector function).

For some applications there is a need to complement already existing and adjusted geometrical navigational structure with new measurements or new measurements and new points. The structure, thus expanded, may be adjusted "anew" as a whole or (which is a more rational process) use the prior adjustment results [Czaplewski 2004]. It has to be noted that the object to be found can be recognize as "a new".

In underwater navigation (although not only there) there may appear a need to identify the false navigation signs. This problem may be solved using the free adjustment methods. In general, a classical adjustment is based on an optimal fitting of marked points (object positions) into the existing, geometrical observation arrangement). On the other hand, it is assumed in free adjustment that the whole measurement structure is internally coherent but not attached to a coordinate system. In such situation the geometrical navigation structure being adjusted, contains the degrees of freedom in respect to the assumed coordinate system.

Taking the above into consideration, in addition to a classical adjustment criterion it is necessary to introduce an additional optimization criterion, associated with growths to coordinates of all points.

This question will be presented in detail in another presentation in E3 session.

4. Simulative Examinations of Underwater Vehicle Navigation

The above presented idea has been examined in simulation way and in details is presented in poster session. It was carried out by the following stages:

- The first stage includes preparation of input data. It was necessary to construct a digital model of sea bottom, which has constitutes the environment for an underwater vehicle in motion;
- The successive stage is programming of deck sonar systems operation, simulation of sonograms, also recording and processing the images;
- The next stage is to determine positions by comparison of measurement images and the map showing the bottom according to image similarities algorithms;
- The last stage covers the questions concerning estimation of measurement results.

4.1. Bottom Spatial Distribution Preparation.

Taking into consideration the work task there were prepared the sea bottom images: a sector of the Gulf of Gdansk area and the tests images of various depths water areas. A determinative, random character of deck echo-sounder operation was assumed; thus it has been operated as follows:

- Simulating the "perfect" parameters of water environment, which were complemented with randomly generated environment interferences;
- Simulating the "perfect" operation of hydro-acoustic equipment, complemented with randomly generated interferences occurring in hydro-acoustic equipment operation;
- Generating the obtained measurements as deterministic values of the resulting parameters of digital sea bottom model, subject to the above mentioned procedures, in addition - disturbed by randomly simulated sonar errors.

4.2. Determining the Position under Observation Applying the Images Similarities Method

The stage covered simulation of the AUV's passing along the assigned route, where the route record was performed by comparing the recorded bottom image with the numerical bottom model basing on various algorithms of images' similarities. There have been also tested the artificial neuron networks applying approximation of a measurement image location in relation to positions of the images which are a part of the teaching sequence.

4.3 The Stage of Position Determination, Applying the Robust Estimation Methods.

This stage makes the essence of the studied tests. The software capable to execute the issues of survey results robust estimation was carried out and tested. It was assumed that the recorded bottom image was burdened with the observed underwater vehicle's position errors, resulting from a quality of the comparative navigation block's operation. The gross errors or random errors may occur. It was also assumed that the position obtained in a result of comparing images (treated as an approximate position) is used for calculation of horizontal bearings and distances to objects resting on sea bottom. Objects were previously identified by the system's operator. Their positions are known and precisely determined. Such an approach enabled to equalize erratic results (gross errors) of bearings and distances measurements as well as equalizing of the observed position, determined basing thereon.

There was assumed that the worked out programme should, first of all, be used for verification of the formulated hypotheses and assumptions, referring to application of the comparative navigation methods for underwater vehicles positioning. The main and principal simplification of the programme is its operation, applying the simulated data or the real data prepared in post-processing. The programme demands operator's recognition of navigation area, skilled identification of the objects visualized on the spatial sea bottom model. For above mentioned simulations there has been prepared digital model of part of sea bottom on polish coast near Gdańsk (see Fig. 7).

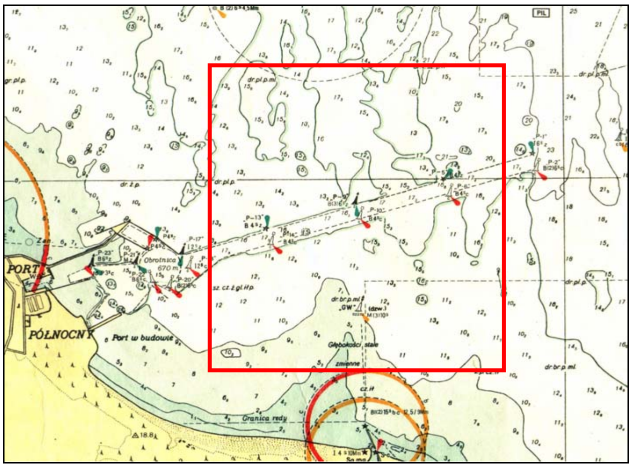

Figure 7. Illustration of test area.

The vehicle carries out observations and takes measurements using multi-beam sounder. Its operator has a possibility of saving measurements records in the programmable memory, processing thereof and using for comparison with a given map.

It was assumed that underwater vehicle moves only above the read-in sea bottom. It may travel along an optional trajectory, determined by a start position, course and marching velocity, dynamically changed within a time of the mission.

4.4 Test Results

All tests have been carried out on several test water areas. The water areas shall differ from each other in configuration of sea bottoms. There have been modelled different and diversified sea bottoms conditions. To equalize the results of measurements and determinations to the bottom there has been selected the natural or artificial, sunk and distinguishing objects.

The system operator executed some runs above every sea bottom area, controlling the underwater vehicle course and speed. Upon carrying out manoeuvres, it is necessary to bear in mind the obvious fact, that the results of applying the comparative navigation methods (image similarities) are better whenever the depth change gradient is at high level.

It was decided that the system should enable determination of horizontal bearings and distances to characteristic objects, located on sea bottom and indicated by the operator. A number of information gathered in this way should assure respective excess of the data number – a number of observations necessary for performance of estimation and accuracy evaluation. The vehicle was moving with a speed of about 5 – 8 knots, while performing all the tests and carried out course changing manoeuvres.

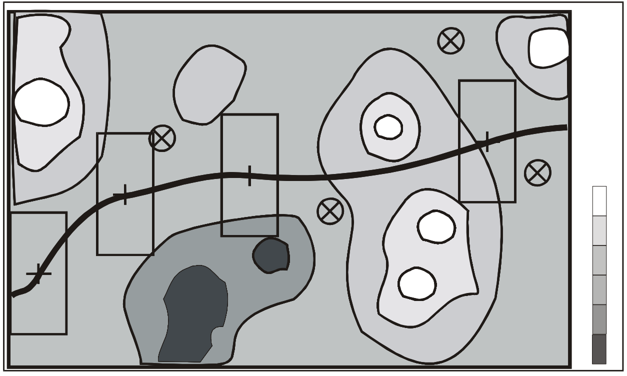

Figure 8. The example of the AUV route.

3. Conclusions

The carried out tests have confirmed the thesis that the measurement estimation methods, adapted from geodesic survey, can be suitable for processing information about the sea bottom, collected by AUV. This allows increasing coordinates' accuracy of objects detected on sea bottom in the post-processing mode. On the one hand it is the information in itself and, on the other hand, may become a basis for precise charts of the bottom.

When analyzing the obtained accuracies it should be taken into consideration that accuracy of results is depend on precision in digitalizing the bottom chart. Thus it may be assumed that an accuracy ranging between 3-5 pixels was obtained, what in case the maps executed in any other scale would fundamentally increase exactnesses. Taking into consideration accuracy of the advanced multibeam sounders one may assume, that in real conditions, at a depth of about 30 m, a pixel's size can be smaller than 1m diameter, and the above means that the accuracies of navigation obtained applying the described method, are better than 10 m.

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